

EXHIBIT 10

Implications of Analytical Techniques for Asbestos Identification

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What is Asbestos? The definition of asbestos is one of the most widely published descriptions of any toxic material. Yet it is perhaps also the most poorly understood. Macroscopically, asbestos is something like pornography; you know it when you see it. Conversely, the definition of asbestos suffers from the same lack of precision in definition as pornography at the microscopic level. The problem occurs for several reasons. The major issue is the incorporation of an aspect ratio in the operational definition of asbestos in regulatory methods. While most regulations clearly specify that asbestos is being regulated and recognize that minerals occur in both asbestos and non-asbestos habits, they specify a minimum aspect ratio or length of the asbestos fiber to be counted. The former is generally lost in the practice of asbestos counting. Rather, the general practice has become that asbestos is identified as any particle that meets the aspect ratio specified in the method and is consistent with the mineralogy or chemistry of the regulated mineral. The aspect ratio thus has become the *de facto* definition of what constitutes asbestos. Many laboratories and industrial hygienists also employ a non-scientific theory — if in doubt, count it, under the misguided assumption that false positives are less significant than false negatives.

The intersection of the dimensions of asbestos and the analytical methods used to count also complicate the issue. Asbestos occurs naturally as fibers consisting of large numbers of fibrils. These fibrils are held together by Van Der Waals forces; relatively weak in comparison to the ionic or covalent bonds that bind atoms together in crystals. The unit width of asbestos fibrils is at or below the limit of resolution of the optical microscope. The lengths of fibers (multiple fibrils) are typically hundreds, or thousands of times the unit fibril dimensions. Thus the magnifications that best elucidate fibril dimensions (>three thousand times) do not permit the entire fiber to be characterized and vice versa. Airborne asbestos is typically under 100 micrometers in length, and less than a micrometer in diameter. Asbestos in bulk mineral samples is typically greater than 100 micrometers in length and several micrometers or more in diameter. The methods and issues involved in the analysis depend on the goal of the analysis: airborne exposure or asbestos content in bulk samples by mass or number.

Phase Contrast Optical Microscopy (PCM) has been used since the 1970's to provide an index of exposure to airborne asbestos. As implemented, this method never included counts of fibers less than five micrometers in length or fibers whose width is below the resolution of the microscope, about 0.25 micrometers. The exposure index obtained, however, did correlate with the incidence of asbestos disease.

Also, as implemented in the U.S., PCM does not discriminate between asbestos and non-asbestos particles. This is not an intrinsic limitation of the microscopic technique, but operational definition employed in the method. The purpose of the definition was to improve the precision and reduce the cost of the analysis. OSHA recognizes this and

permits discriminate counting in circumstances where the identity of the fibers being counted is questioned. The definition is not a problem when asbestos fibers are being counted in industrial environments where asbestos is being processed, or when the airborne fiber levels are in the fibers/ml range, but it becomes an issue in environments where asbestos is not being processed, where other sources or types of fiber predominate, or when fiber levels approach those of ambient air. The issue is two-fold: one is the simple over counting problem; the other stems from the rules employed — count the first hundred fibers, or hundred fields. Thus innumerable PCM counts have been reported which contain no asbestos fibers in the count. As a result, the significance of the asbestos concentration present, if any, is obscured.

In the 1970's, Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), and Energy Dispersive X-ray Spectroscopy (EDS) became available commercially. With these instruments, the chemistry and crystal structure of mineral particles could be determined and a major portion of the fibers not counted by the PCM method could be counted. About the same time, interest in assessing the environmental significance of asbestos grew. Unfortunately, counting the fibers missed by the PCM and identifying the fiber types found; not refining the PCM method, became the mission. As a result, enormous resources have been devoted to analyzing particles that are generally regarded as insignificant with respect to health.

Little or no attention is paid in most laboratories to determining if a sample contains cleavage fragments or asbestiform fibers. The OSHA and AHERA regulations are clear: the asbestiform varieties of the regulated minerals that meet specific size and shape criteria are to be counted. The non-asbestos analogs or varieties are not regulated and therefore are not to be counted regardless of their size and shape. In contrast, anything that meets the minimum specified aspect ratio and chemistry of the regulated asbestos minerals is included in the reported count as asbestos. Thus the size and shape of the particle has become the *de facto* definition of asbestos, rather than the criteria by which asbestos particles are included or excluded from the count. The difference is insignificant when determining exposures in an environment with a significant source of asbestos fibers, but has had extraordinary impact when determining exposures in mixed mineral or environmental exposures.

In the early days, many laboratories did not have EDS spectrometers or experience with selected area electron diffraction (SAED), and the problem was pervasive for both chrysotile and amphibole minerals. Today, the major problems involve identification of amphibole minerals and separation of their asbestos habit from the non-asbestos habit(s). With the current alarm about potential exposures to non-regulated asbestiform minerals, virtually all of which have both asbestiform and non-asbestiform habits (growth forms), the issues caused by casual definition (at the microscope) of asbestiform with respect to amphiboles will affect major portions of the crushed stone and mining industries.

Where is Asbestos found?? The regulated asbestos minerals are all ferro- or magnesio-silicates, and members of the amphibole or serpentine mineral families. The asbestos forms of these minerals occur as secondary or accessory minerals in metamorphic and

igneous deposits where stresses within the earth have fractured the rocks. Chrysotile is primarily found as veins in host ultrabasic rocks, but commercial deposits have also occurred in serpentinized dolomitic limestone. Amosite and crocidolite are usually mined from metamorphosed ferruginous sedimentary formations, while tremolite/actinolite and anthophyllite are associated with highly metamorphosed ultrabasic rocks. Folding, faulting, or shearing has evidently played a major role in the formation of asbestos deposits. Deposits of asbestos of commercial significance are infrequent. Trace to minute quantities of asbestos can be found locally in almost any metamorphic or igneous mineral deposit. Thus, it is virtually impossible to certify a quarry or mining operation as asbestos free. Review of the geological maps of the U.S. illustrates that metamorphic and igneous rock formations underlie the majority of the densely populated areas in the country.

Since all amphiboles have tendencies to fracture into elongate particles as a result of the orientation of their intrinsic fracture planes, any occurrence of amphibole will produce particles having aspect ratios greater than 3:1. Further complicating the issue is that amphiboles can also form in acicular or needlelike habits. Therefore, if, as practiced by many laboratories, any amphibole particle with a length to width ratio of 3:1 is classified as asbestos, the analysis of mineral samples for asbestos in most metamorphic deposits would produce positive but erroneous results.

Recent controversies over supposed tremolite asbestos in talc, limestone quarries and playsand; reports of tremolite (richterite and winchite) asbestos fibers in Libby Montana, and tremolite asbestos in air samples from vermiculite mines in Virginia, have all been driven by laboratory results that were either completely erroneous, or which grossly exaggerated the amount of asbestos present.

What are the Solutions? *Pro Active Position:* The crushed stone and mining industries need to recognize that their products are and will continue to be scrutinized by groups who view their mission in life as the elimination of asbestos in any concentration from any product. These groups do not recognize the mineralogical distinction between asbestos and non-asbestos forms of any mineral, let alone the amphiboles. They ignore the fact that if all amphiboles were equally potent, the asbestos diseases would not be restricted to people with significant exposures to asbestos. Industry needs to take the initiative in evaluating their products and determining that they do not contain asbestos, or that the use of the product does not generate significant exposures in the workplace or to the ultimate consumer. Industry associations should develop testing protocols that members can employ to certify that their products are "asbestos free" or contain diminimus quantities of asbestos. For products containing measurable quantities of asbestos, protocols for testing and certifying the potential exposures should be developed and standardized. Industry should take the lead in involving state and federal agencies to recognize these protocols and advising the public that they are based on sound scientific procedures.

Robust Analytical Procedures: Reliable methodologies for investigating the abundance of asbestos in air and bulk samples exist. Techniques for evaluating minerals from the

quarry face to the ultimate products exist. Industry (as a consumer) needs to learn to evaluate the qualifications of the laboratories used in determining whether asbestos is present in a mineral sample or air sample. Industry needs to assure that any samples collected are representative of the mine face, quarry or product, and that the sample preparation techniques validly extract the quantity of asbestos present. If potential exposures are being evaluated, the method of determining the respirable dust fraction is critical. Finally, and most importantly, the microscopic analysis must recognize and differentiate between the asbestos form and non-asbestos form of minerals before the decision to include or exclude the particle in the estimate of the asbestos content is made. If a laboratory makes that decision simply on the basis of the size, shape, and mineral identity — avoid them. Laboratories that are unwilling or unable to provide photographic documentation of the particles identified as asbestos should be avoided.

What are the Proper Procedures? The procedures which must be considered are not limited to those used by the microscopist, but include sample collection and preparation. None of these steps are independent of the others; there should be interaction from the mine through the microscopist to achieve a quality analysis.

Collection: While this is the most basic step in the process, it is also the most critical. Depending on how the sample is collected, or where it is collected, places limits on the reliability of the analytical data. The first step is to decide why the sample is being collected — is it for product characterization, on-going product quality testing, exploration, or possibly for use in selective mining? Various organizations (such as ASTM) have developed specifications that can be used to sample product streams for on-going product quality testing. However, for operating mines and quarries where the ore body has already been delineated through exploration, examination of the quarry/mine face is the most logical sampling point. The California Air Resources Board has recently proposed legislation requiring mine/quarry operators to have the site surveyed prior to mining or grading (www.arb.ca.gov/regact/regup01.htm#asbes).

Preparation: Sample preparation should be conducted in such a way as to remove interfering minerals (when necessary) and to separate the particles into sizes that are appropriate for a particular analytical method. The sequence to be followed (matrix reduction and size separation) should be based on a knowledge of the material to be tested as well as on the end use of the analytical data. Where the number of asbestos fibers (as opposed to the mass of the fibers) is significant, it is important to minimize or eliminate steps that will disaggregate or fracture the fibers. The mass of any separated fraction must be carefully determined.

After the sample has been dried, examine the sample. For micaceous samples such as vermiculite, separate the low density materials from the remainder of the sample using a water bath. The floating materials are generally coarse and suitable for optical microscopy. Other materials may first be washed in 1N HCL to remove carbonates and other acid soluble materials. The remaining materials should be suspended in water and the fine fraction separated from the remaining material through sedimentation. The fine fraction (generally smaller than 50 – 70 μm) is suitable for electron microscopy. The

remaining materials should be sieved at 60 mesh (250 μm) to create a fraction suitable for optical microscopy ($> 250 \mu\text{m}$) and another for electron microscopy ($< 250 \mu\text{m}$).

Analysis: We believe a four step procedure to be the best methodology. This is done because in real-world mineral samples asbestos is present as coarse bundles that are readily observed by simple optical screening (stereo optical microscopy), PLM (Polarized Light Microscopy), or SEM (Scanning Electron Microscopy). If coarse enough, the asbestos will be present as large ($>0.5 \text{ mm}$) particles which can be extracted, weighed, and confirmed optically as asbestos. The finer particles are analyzed by PLM, SEM or TEM (Transmission Electron Microscopy) depending on their size.

In each of these techniques, we rely on the criteria developed by the Bureau of Mines (Virta 1985; Campbell, et al, 1977), and formalized by EPA (EPA/600/R-93/116, 1993) and OSHA (29 CFR Parts 1910 and 1926) for optical microscopy. As noted by OSHA and others, the defining criteria for asbestos on a bulk basis will generally carry through to some, although not all, particles of asbestos observed in the SEM or TEM.

In the SEM, we rely on the observation of cleavage faces, fracture characteristics and size to discriminate cleavage fragments, along with the observation of curved fibers with splayed or separated ends, appearance of longitudinal striations and the absence of 110 cleavage and 100/010 cleavage steps.

Using any of the analytical methods, it is important that the physical characteristics be analyzed in addition to determination of the aspect ratio.

In the TEM, we rely on the flow chart (see Figure 1), unless asbestos has been identified by optical or scanning electron microscopy, in which case we revert to morphology. The simpler morphology rules speed up the analysis for cases where we know asbestos is present.

When the TEM is used to determine the mineral identification, a combination of morphology, chemistry (EDS) and crystal structure (SAED analysis) are required. The EDS must be collected long enough to maximize peak height relative to the background, but not so long as to damage the crystal and minimize the chance of observing sodium in the spectrum. Diffraction pattern analysis is necessary to identify intergrowth fibers (such as in talc samples) that are not, at this time, regulated fibers. These intergrowth diffraction patterns are complex, but have been discussed by Virta (1985) and Stemple and Brindley (1960). These patterns require skill to resolve; one cannot simply ignore some spots as strays and focus on others that fit a preconceived notion of the fiber.

The flow diagram (Figure 1) is a synthesis of the identification criteria and the observations by numerous researchers including Zussman, Campbell, Nord, and Ring. Asbestiform particles exhibit features such as curved fibrils, bundles with splayed ends and parallel sides with well-defined terminations. Defining structural criteria for asbestos fibers are the presence of microscopic twinning, thin crystals, and internal defects which show up as streaking in certain diffraction patterns and twinned spots in others.

Finally, the size and aspect ratio distribution of the amphibole species identified in the SEM is evaluated and compared to that of known asbestos distributions as characterized by Gibbs and Hwang, Wylie, and others. These populations permit direct comparison of characteristics of the amphiboles in question with those of asbestos and nonasbestos populations whose biological significance has been studied (Berman, et al.).

Conclusion A rigorous analysis of the asbestos content of air or bulk samples is viewed by some as too expensive, by others as too hard, and still others as needless because a simpler analysis will satisfy their philosophical or political perspective — if we eliminate potential exposure to anything with a certain shape, we will most certainly eliminate asbestos exposure. In many cases, this viewpoint is driven by fear and distrust of industry. In other cases, it is driven by a genuine fear, albeit unfounded, of anything that resembles asbestos. In other cases it is driven by money: our system lines the pockets of lawyers and experts who play on the fears of asbestos.

In the case of the crushed stone and mining industry, the problem is aggravated by a general lack of understanding of the significance of the methodology used to determine the asbestos content of rock or air samples. Companies routinely receive inadequate or incorrect analyses because of the failure by the laboratory they use to adequately understand the complexity of the issues involved in separating the asbestos forms of minerals from the non-asbestos forms.

The result of this ignorance and misunderstanding has been costly to society in many ways. Huge sums of money were spent in the 1970's litigating and remediating non-asbestos grunerite tailings being discharged into Lake Erie. Crayons, attic insulation, play sand, hair dryers and many other products have had scares associated with the allegations of asbestos supposedly found in them. The 1980's and 1990's were the decades of "asbestos in schools". Billions of dollars were spent removing asbestos from schools, and litigating the responsibility for the removal and replacement materials. Predictions by then head of Mt. Sinai School of Medicine of an epidemic of asbestos disease due to the mere presence of asbestos in schools has proven to be unfounded. Today the life of the vermiculite, talc, and zeolite industries are being threatened. The next decade may well be the decade of the crushed stone and mining industry.

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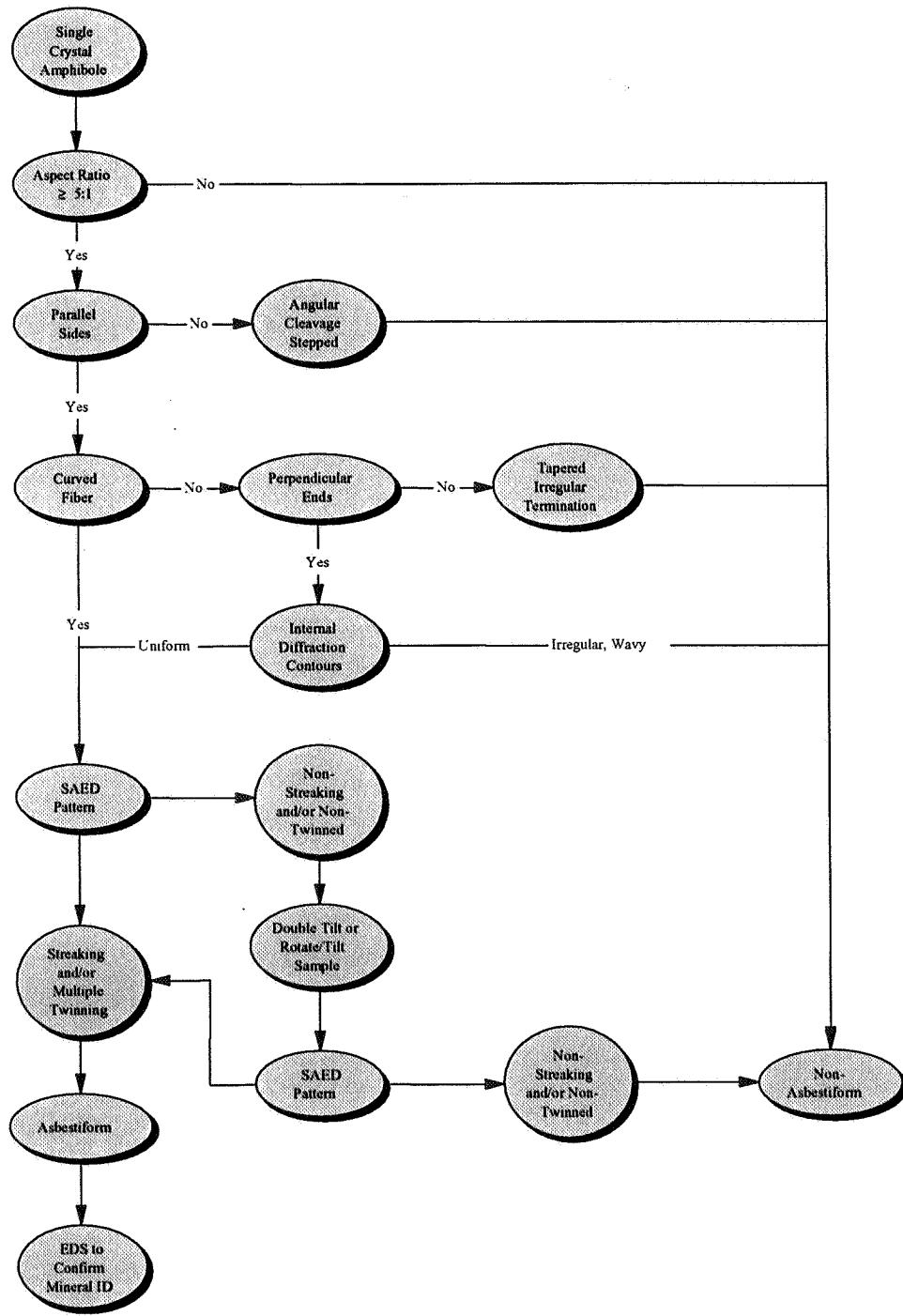


Figure 1. Detailed analytical procedure for use in delineating asbestiform fibers from cleavage fragments.